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Lessons Learned during the Refurbishment and Testing of an Observatory after Long- term Storage

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Background

- The Triana mission development proceeded for 21 months before it was abruptly postponed in 2001.
- The duration of the shut down was significantly longer than anticipated and the Observatory was stored for nearly a decade.
- The Triana observatory was stored in “stable suspension” in a cleanroom under nitrogen purge.



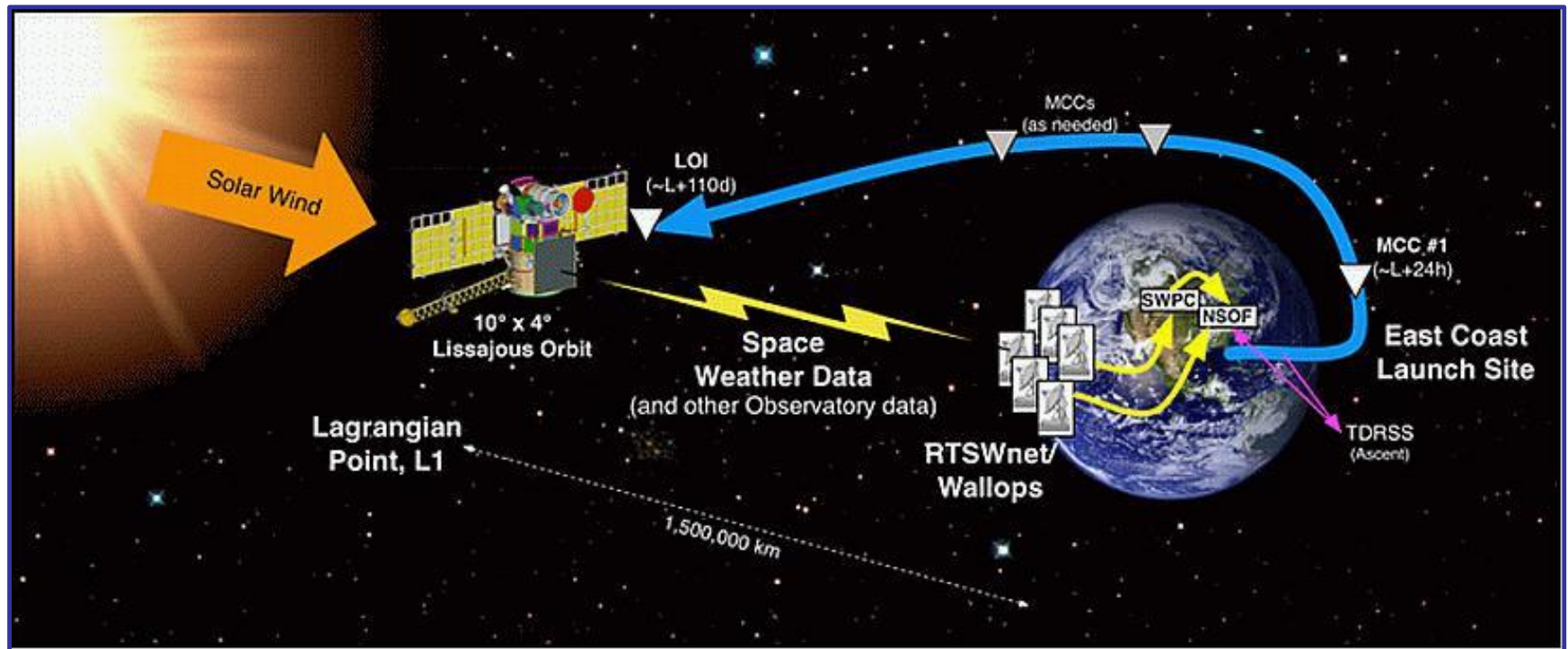
Background

- After the mission was placed into storage, it was renamed DSCOVR (Deep Space Climate Observatory) and the primary science was changed from Earth science to space weather.
- The Deep Space Climate Observatory (DSCOVR) is now a joint mission between NASA, NOAA and the U.S. Air Force.
- After the nearly decade of “stable suspension” NASA refurbished the DSCOVR satellite and instruments.



Background

- DSCOVR, currently stationed at the first Sun-Earth Lagrange point (L1), is designed to provide advanced warning of solar wind activity that could damage low Earth orbiting satellites and ground systems. DSCOVR also hosts two secondary instruments for Earth observations.





Lessons Learned

- Documentation
- Software/modeling
- Hardware
- Propulsion
- Thermal Vacuum Testing
- Thermal Blankets
- Thermal Coatings



Documentation

- Due to the abrupt shut down, data stored on various computers was not transferred to a central repository.
- Hard copies of documentation were often not properly stored.
- When the DSCOVR mission ramped up a decade later, the documentation for the spacecraft was not readily available or no longer existed.



Documentation

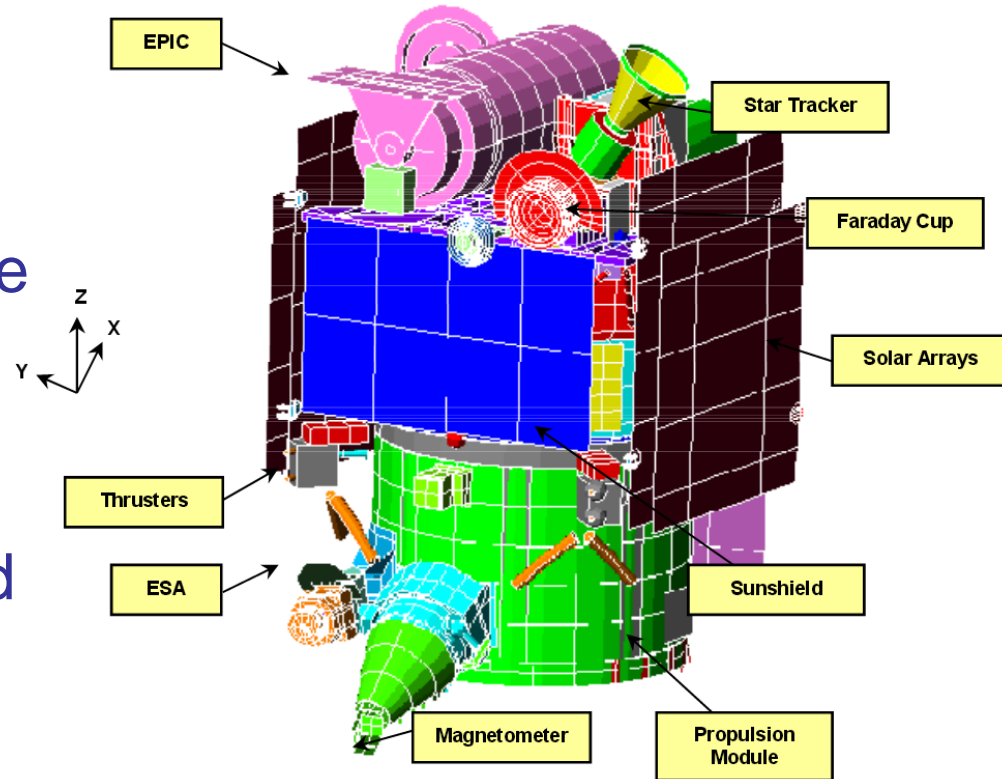
Lessons Learned:

- *Provide adequate time to allow for data collection and proper storage of data from all subsystems, including contractor support teams.*
- *Protocol should be established to govern the shutdown of a project / mission, with data deliverables to the project Configuration Management group from every discipline.*
- *Data stored by contractors should be listed as a deliverable.*



Software/Modeling

The thermal models were originally built in Thermal Synthesizer System (TSS) and SINDA/FLUINT, but were rebuilt in Thermal Desktop using the existing thermal models and available documentation for the rebuild process.





Software/Modeling

- Certain portions of the heritage models have the surfaces integrated in to the Thermal Desktop model with the capacitance and conductance calculations integrated via INCLUDE files.
- The instrument models obtained from the delivered TRIANA data were basic instrument models, with very little fidelity.

Lessons Learned:

- *With discrepancies in the available documentation and missing information it is necessary to examine the flight hardware to verify the thermal model.*
- *Sufficient documentation and/or access to the model originator is needed to rebuild and update the models.*



Hardware Changes

- The instruments were removed from the Spacecraft for refurbishment.
- The bulk of the avionics had to be de-integrated from the Spacecraft for refurbishment.
- The ESA instrument was relocated from the end of the boom to the propulsion module.
- An extension was added to the end of the deployable boom to host the magnetometer.
- The reaction wheel assemblies had magnetic shields added to them to meet the new science requirements.
- Choke rings were added to the omni antennas.
- A new lithium ion battery was installed.
- Struts were added to strengthen the instrument deck.



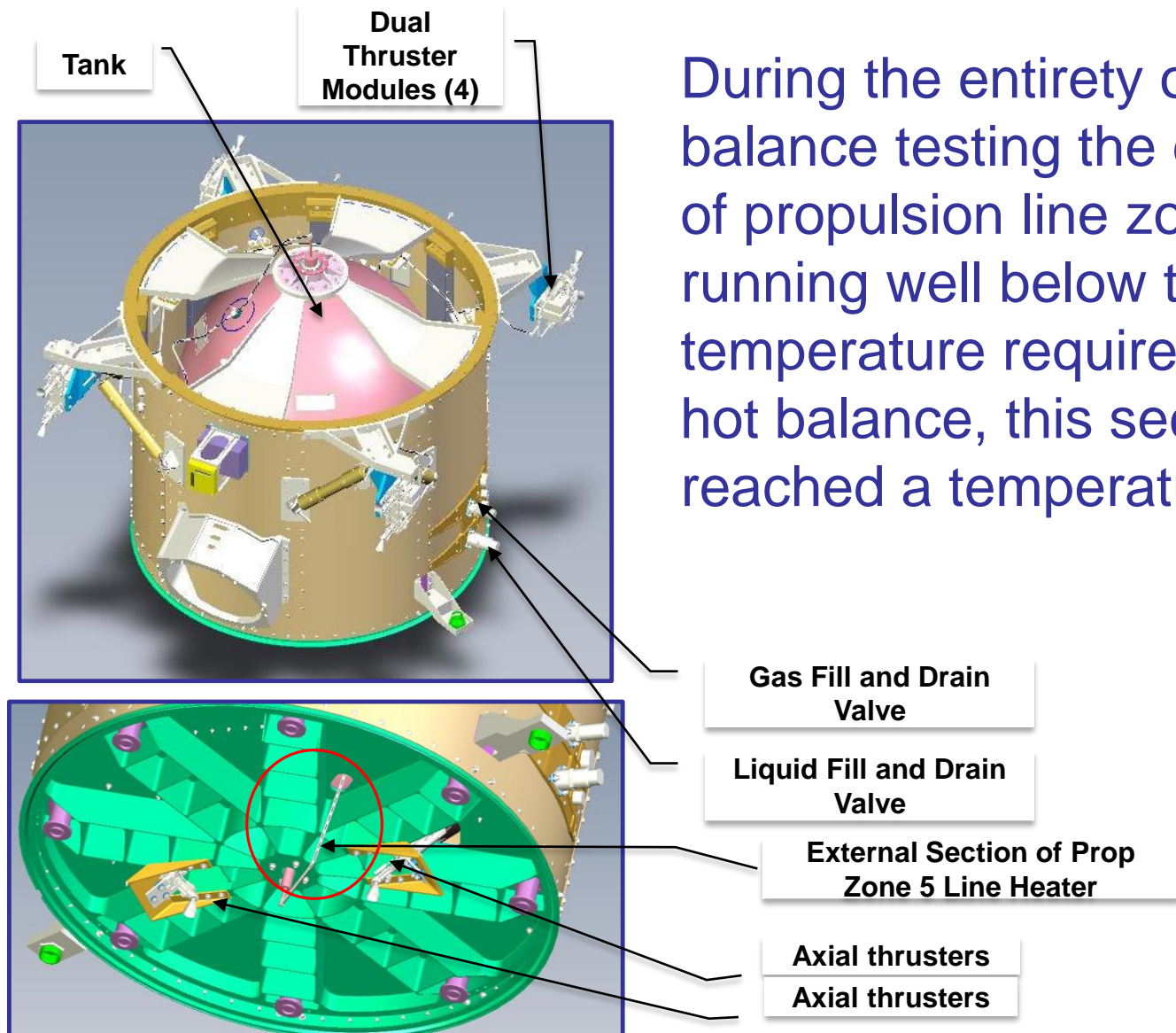
Hardware Changes

Lessons Learned:

- *Using existing hardware with new primary science objectives and requirements is likely going to drive multiple hardware changes that may not initially be known.*
- *With numerous hardware changes and broken thermal interfaces thermal balance is highly recommend.*



Propulsion - Module Hardware

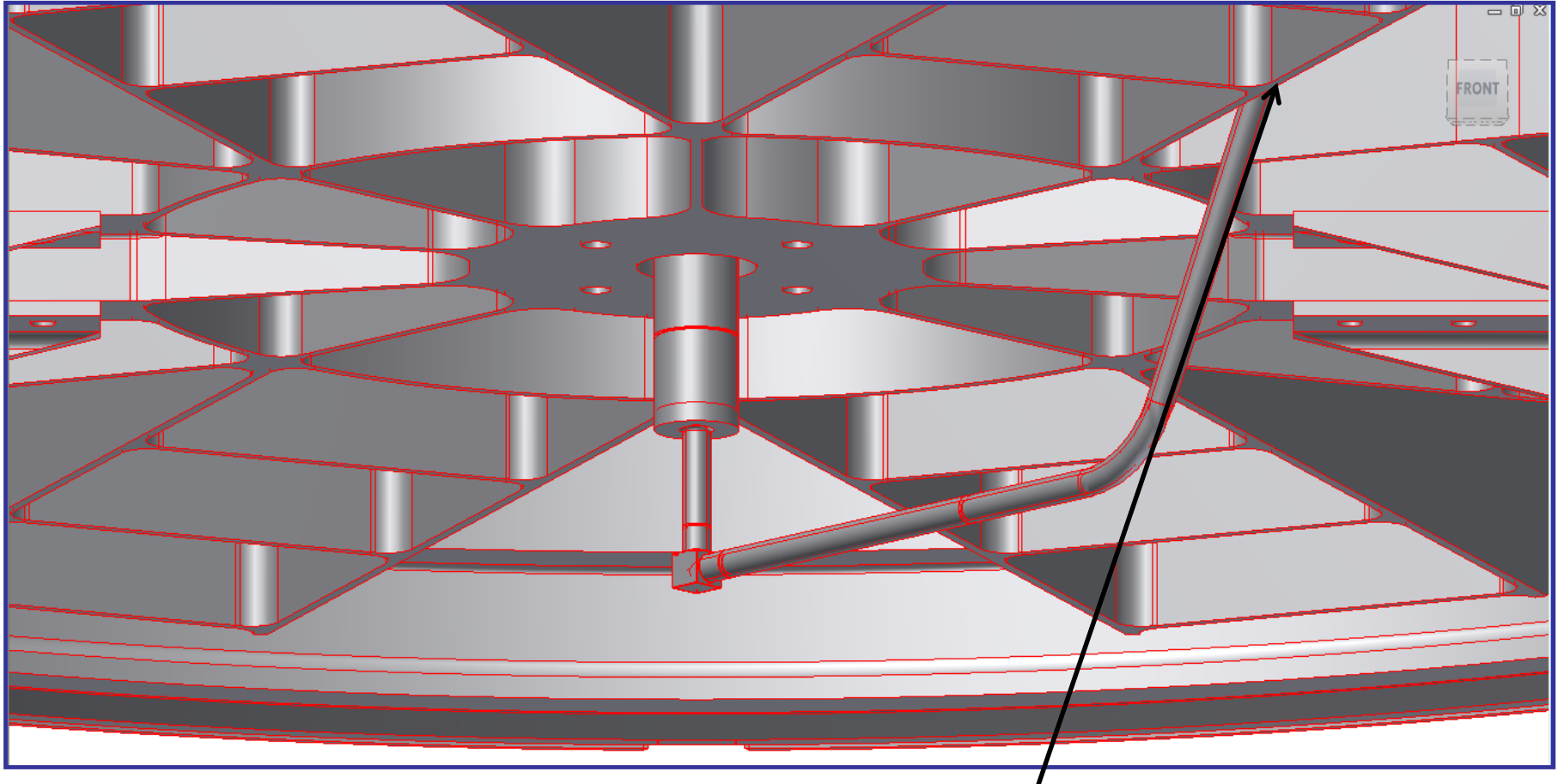


During the entirety of the thermal balance testing the external run of propulsion line zone 5 was running well below the minimum temperature requirement. During hot balance, this section of line reached a temperature of $+2.3^{\circ}\text{C}$.



Propulsion

External Run of Propulsion Line Zone 5



Propulsion Line Heater Zone 5 Heater Control located inside the prop module
Med Control Thermistor On @ 24°C Off @ 26°C
Low Control Thermistor On @ 18°C Off @ 20°C



Propulsion

- Further examination of the thermal balance test data from TRIANA testing revealed the same propulsion line 5 behavior.
- On the external run, an auxiliary dual element heater with a pair of series redundant thermostats had to be installed over the existing line 5 heater.
- The added thermostats were chosen with control points lower than the existing electronic controller set-points so that the auxiliary heater wouldn't impact the function of the existing heater.
- Structural analysis had to be performed to assure that there was no impact due to the added thermostat, heater, and aluminum tape masses.



Propulsion

- Since there was no readily available flight experience with this layered construction, an Engineering Development Unit (EDU) was fabricated and tested.
- Ambient testing of the flight installed auxiliary heater, as well as the underlying existing heater, was performed to verify operation.



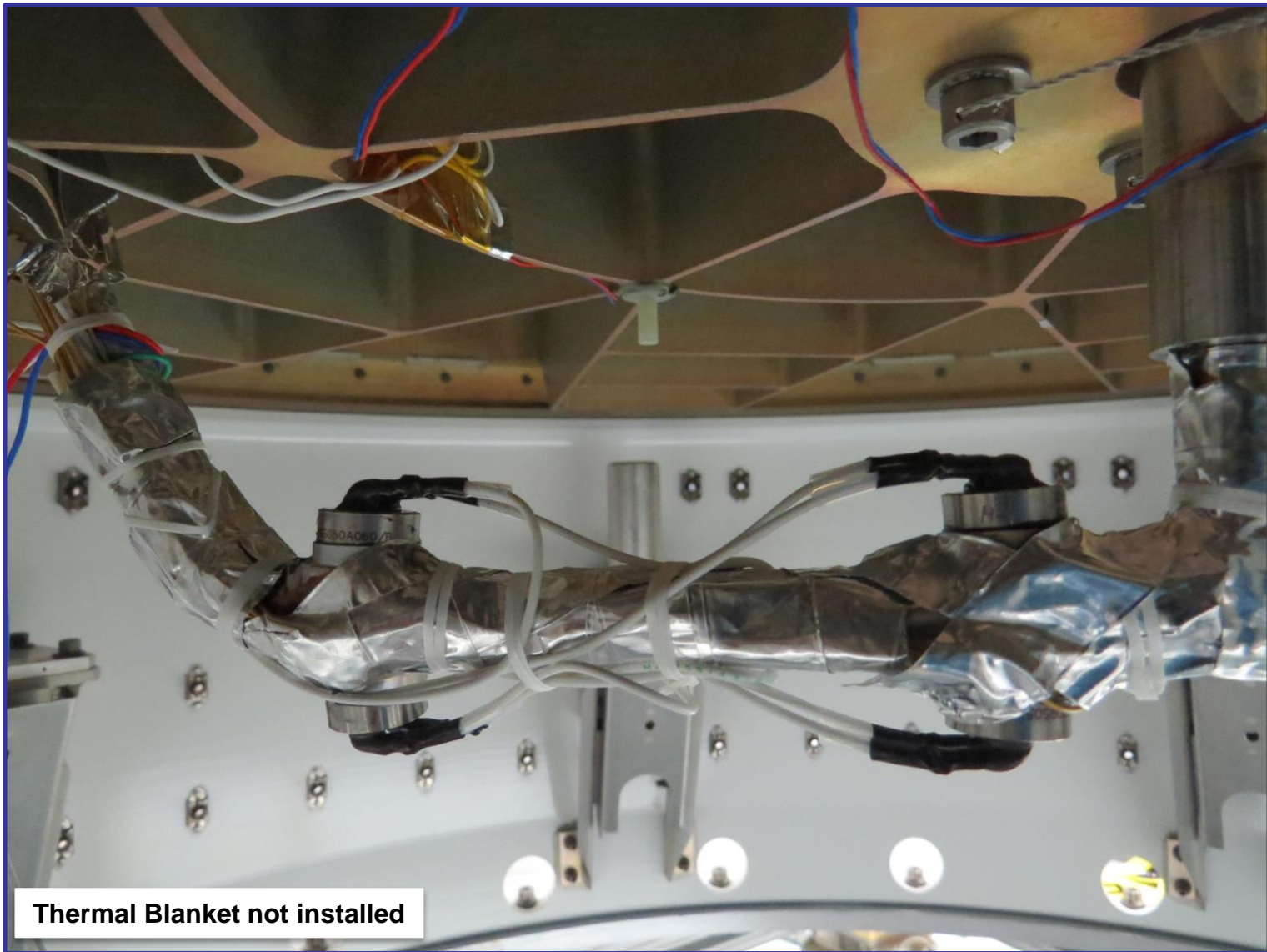


Propulsion

- Wires had to be run to the bottom of the propulsion module to power the flight auxiliary heater.
- The high gain antenna and the prop module access panel had to be removed to gain access to the inside of the prop module for wire routing.
- Several mli blankets had to be removed to install the auxiliary heater.
- The flight installation had to be tested.



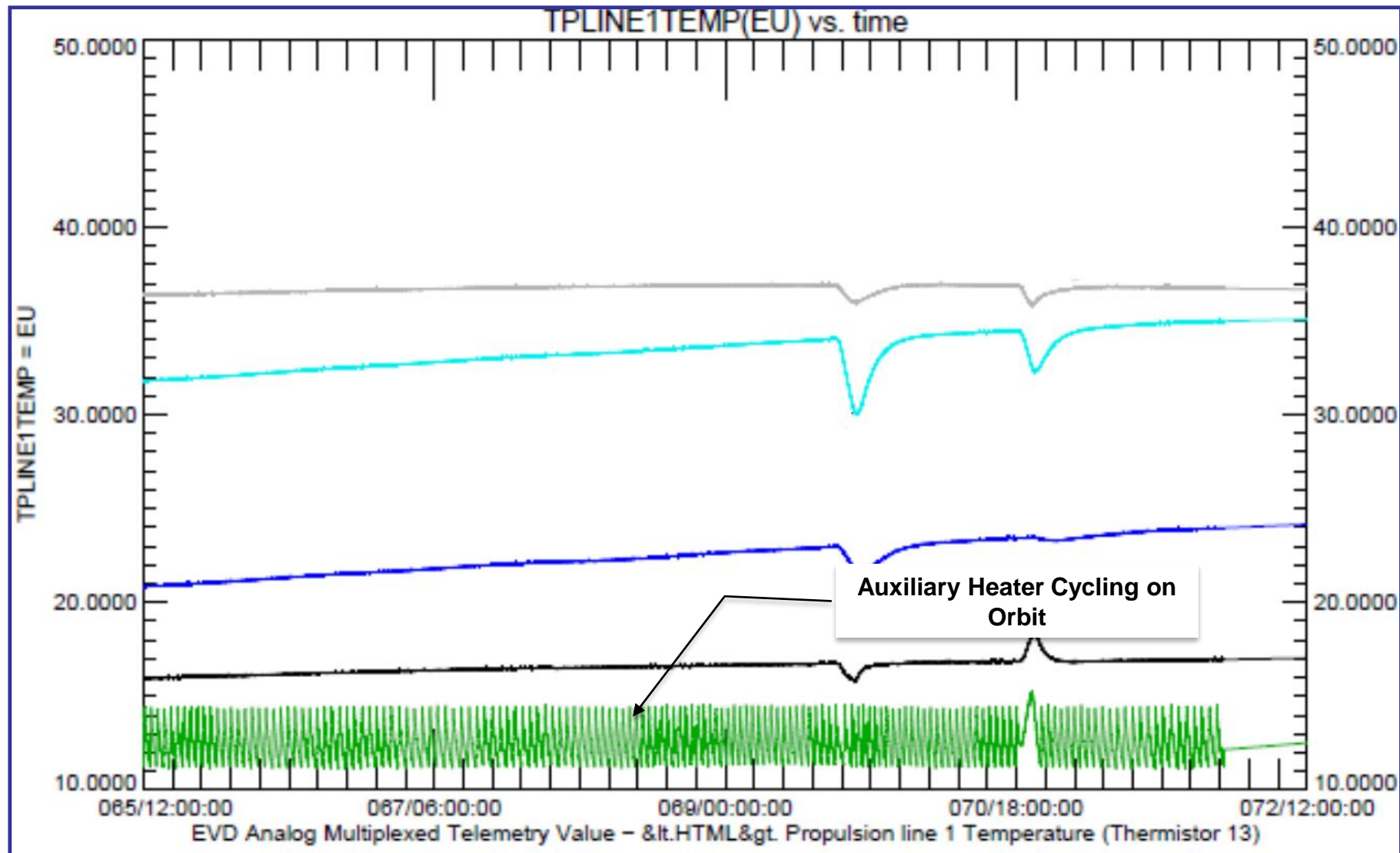
Propulsion - Flight Installed Auxiliary Heater



Thermal Blanket not installed



Propulsion - Auxiliary Heater Flight Data





Propulsion

Lessons Learned:

- *The successful test program demonstrated acceptable function of the additional heater and thermostats, while preserving the functionality of the underlying heater.*
- *When possible separate propulsion line heater zones should be installed on interior and exterior lines.*
- *If a propulsion line heater zone spans the interior and exterior interface of a spacecraft use doublers to enhance longitudinal conduction and locate control sensor at the coldest section of line.*



Thermal Vacuum Testing

- Several power inconsistencies between test data and the systems level power budget were identified during thermal vacuum testing.
- Further investigation yielded information that the current monitors for the reaction wheels were incorrect and could not be used since they were not calibrated.
- The design of the DSCOVr current monitoring system has multiple components on a single current monitor.
- Several monitors include both a heater service and multiple power dissipating components.



Thermal Vacuum Testing

- During the TRIANA testing program, there were several thermocouples installed on various internal propulsion components (tanks, lines, propulsion control module). When the program was abruptly shut down, the ends of these TC wires were cut such that the TC labels (numbers) were not preserved.
- Due to some significant power uncertainties, the overall correlation posed a significant challenge, and the correlation was unable to provide a good match between test and model predictions.



Thermal Vacuum Testing

Lessons Learned:

- *Always preserve thermocouple labeling until you are sure they will never again be used.*
- *All current monitors should be verified against independent measurements during any component level testing.*
- *Make sure that the test environments will bound the worst hot and cold flight environments such that the test results directly validate the adequacy of the thermal design.*
- *Add the appropriate margin to your correlated model flight predictions.*



Thermal Blankets

- Germanium missing from most areas of germanium black Kapton MLI; replaced outer layers.
- Several blankets totally missing.
- Had to figure out the original location of many others.





Thermal Blankets

Lesson Learned:

- *MLI in long term storage should be in a humidity controlled environment and handling minimized.*
- *Thermal Project Engineer should understand and inform Project Management regarding the scope and complexity of thermal blanket fabrication and installation.*
- *Individual blanket designs and fabrications should be identified with sufficient time allocated for these activities in the I&T schedule.*
- *Individual blanket installations should be identified in the I&T schedule as any other hardware installation task, rather than specifying a general time period for overall installations.*



Thermal Blankets - Grounding

Lesson Learned:

- *The design and implementation of blanket ground wire attachments should be completed prior to blanket installation.*
 - *Provides for blanket grounding and grounding measurements during the blanket installation task. By doing so, blanket installation can be fully completed during the scheduled installation session.*
 - *Ungrounded blankets can possibly interfere with other integration activities.*



Thermal Blankets - Mechanisms

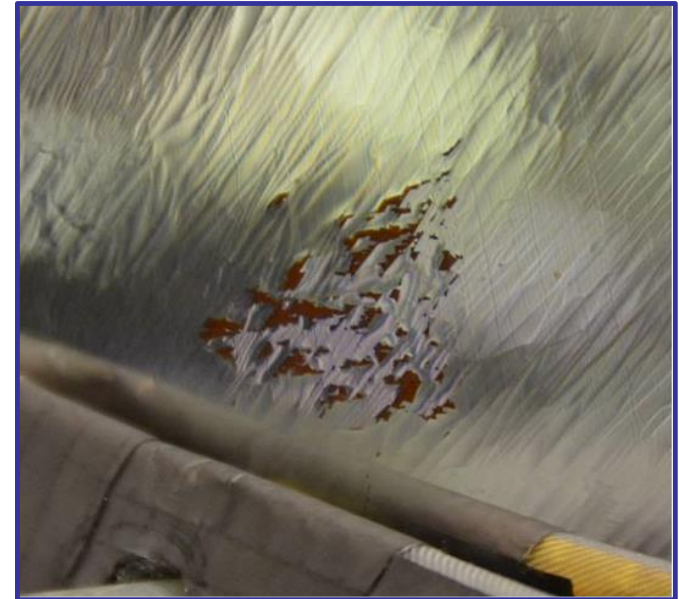
Lessons Learned:

- *For blanket applications associated with moving mechanism parts, blanket coverage and installation should be adequately discussed prior to the blanket installation. After installation, blankets should be critically inspected by all required discipline engineers so that any blanket modifications can be performed to finalize the installation.*
- *Up-front planning can minimize or eliminate cost and schedule impacts resulting from blanket modifications required later in the program.*
- *Blanket modifications at higher levels of assembly later in the program can prove to be challenging.*



Thermal Coatings

- Most thermal control surfaces showed damage due to mishandling, although the optical properties hadn't changed during storage.
 - NS43C white coatings touched up with Z93C55 white paint.
 - High temperature E-glass MLI near the thrusters were shedding particles; required stainless steel shells be installed to contain the particles.
 - Phosphoric-acid etched nickel inside the NISTAR baffles began flaking. Instrument was taken apart, surfaces stripped and recoated with Z306 black paint.
 - Root cause of shedding not clear.





Thermal Coatings

Lessons Learned:

- *Schedule and budget for increased cleanings and inspections of coatings throughout the I&T campaign.*
- *Early on in the refurbishment consider stripping and re-applying coatings to all shedding surfaces.*



Acknowledgements

- DSCOVR mechanical team.
- DSCOVR coatings group.
- DSCOVR contamination team.